10.3 The Arid Scenario: Inselbergs in the Namib Desert Are Rich Oases in a Poor Matrix (Namibia and South Africa)

N. JÜRGENS and A. BURKE

10.3.1 Geography and Geology

Topographically uniform, the Namib Desert consists of vast plains of low altitude, stretching from the coast some 60 to 120 km inland. Further inland, the desert is often fringed by a steep escarpment, leading up to a plateau attaining altitudes of 1000 to 1800 m. The desert is geologically characterized by very old rock formations and a predominance of erosional processes since the Cretaceous. These processes shaped the wide plains, tilted towards the Atlantic Ocean.

The homogeneous pattern is interrupted by the presence of several archipelagoes of inselbergs. These are mainly formed by basaltic pipes and dikes, and granitic plutons. Exceptionally, also quartzite (Hartmannsberge), basaltic plateaus (Damaraland), and metasediments (e.g., gneiss, schist and dolomite) (southern Namib) contribute to the formation of inselbergs, often in combination with old intrusions. The inselbergs are generally forming an important contribution to the structural diversity of the Namib Desert, but their occurrence is not evenly scattered. At least five important centers of inselbergs or archipelagoes of inselbergs can be distinguished in the Namib Desert region:

1. Northern Namib inselberg archipelago,
2. Central Namib inselberg archipelago,
3. Great Namib Dunefield inselberg archipelago,
4. Southern Namib inselberg archipelago, and
5. Namaqualand-Richtersveld Sandveld inselberg archipelago.

Other, less prominent or less isolated groups of inselbergs are found in Damaraland (mostly basaltic plateaus). An inland part of the Namib Desert, the East Gariep Namib in the southeast of Namibia (Jürgens 1991),

as well as the adjacent arid Namaland contain a number of arid inselbergs (Tatasberg, Brukkaros, Karasberg). Similar to these, inselbergs are found in the adjacent Bushmanland of the South African Northern Cape Province. Using a somewhat wider definition of inselbergs, a number of isolated plateaus, e.g., in Kaokoland or the huge sandstone plateau of the Waterberg, should also be mentioned. However, these more humid regions are outside the focus of this chapter.

More detailed descriptions of the major inselberg archipelagoes are presented in the section on flora and vegetation, while the following section discusses some general information on the geographical and edaphic features of inselbergs.

10.3.2 Geomorphological Features

The shape of inselbergs varies according to their lithology and geological history. While phonolithic pipes and granitic plutones are generally more or less circular in extension, dolerite dikes can form linear inselbergs of a few hundred meters to about 100 km (!) length (Fig. 10.3.1).

Fig. 10.3.1 Dolerite ridges form linear inselbergs of several 10 km length in the central Namib desert plains

Very unusual is the horizontal extension of the Messum crater between the Brandberg and the coast, forming a crater-like ring of mountains, interpreted as a volcanic pipe. Another circular ring structure is represented by the Roter Kamm, a meteorite crater in the southern Namib Sperrgebiet.

Looking at the vertical structural patterns, the crystalline inselbergs of the Namib Desert region show the same rounded shapes as elsewhere. Depending on the degree of fragmentation and the length of their exposure to weathering agents, the structures can vary from huge granite domes with smooth surface (Fig. 10.3.2 und 10.3.3, Spitzkoppe) to deeply dissected arrangements of boulders (koppies). In contrast to other regions (cf. Porembski, Chap. 10.1, this Vol.), the differentiation between granite domes with steep slopes and flat shield inselbergs shows no correlation to climate, but seems to follow a regional pattern of geological units. However, extreme examples of shield inselbergs can be observed in those parts of the Namib which are exposed to high wind speed. In these regions, sand-blasting results in aerodynamic planation of granite domes (Fig. 10.3.4 and 10.3.5). Bimodal structures are found, where inselbergs in aerodynamic landscapes are high enough, to form dome-shaped tops in zones at higher altitudes above the impact of sand-blasting (e.g., Uri-Hauchab).

A very different type of inselbergs are plateau inselbergs, formed by sedimentary or basaltic rocks with constant-angle erosion. Their shape is controlled by the extension of sediment or basaltic layers and the erosive energy of the catchment areas of adjacent river systems, often controlled by older tectonic forms.

Again a different structure is provided by the linear inselbergs of the dolerite dikes of the central Namib Desert (Fig. 10.3.1). The hard dolerite filling of the dikes is most resistant to erosion, while the contact zone and surrounding crystalline material form a basement on either side of the dolerite ridges.

Locally, surface structures on inselbergs are strongly dependent on lithology. Rock pools are frequently found in crystalline rocks, while the formation of small channels, cut into the rock surface, seems to be dependent on the presence of cyanobacteria. Both structures are characteristic for the summer-rainfall part of the Namib Desert. In contrast, granite domes in the winter-rainfall climate of the southern Namib show green algae and lichens covering larger surface areas of the rock, although broader linear arrangement of these larger carpets can also be observed on steep slopes.

10.3.3 Soils

In humid regions, inselbergs differ edaphically from their surrounding landscapes, because they possess a high proportion of rocky surface without soil formation. However, in the desert environment, the soils of the surrounding zonal habitats also have to be classified as aridisols, inceptisols, and other substrate-dominated soil types of weak soil genesis.

Important large-scale soil gradients in the Namib are observed along coast-inland transects (Jürgens et al. 1997) where coastal predominance of NaCl is replaced by predominance of Ca_2SO_4 and, still further inland, $CaCO_3$ (Martin 1963; Scholz 1967). Along the coast, sand fields are dominated by white quartz sands, while increasing importance of iron coatings is observed with increasing distance to the coast, resulting in more reddish or brownish colors. Important dune fields are found in the southern central Namib (Great Namib Erg), the southern Namib (Diamond Area or Sperrgebiet), and the northern Namib (Skeleton Coast) (sequence reflecting decreasing importance). While soils are generally above pH 7 in the summer-rainfall parts, acid soils are somewhat more important in the winterrainfall part of the Namib Desert.

Owing to the concentration of runoff water in local catchment areas, rocky inselbergs harbor microhabitats of high and/or all-year-present soil humidity generating processes of intensive rock weathering and accumulation of organic matter. These humid microenvironments create – in an arid macroclimate – relatively better-developed and more diverse soil and vegetation types on inselbergs than in the surrounding zonal landscapes. In spite of the very high ecological importance of these wet pocket soils, no scientific data on the properties of these soils seem to exist.

Fig. 10.3.2. Granite dome of the Spitzkoppe, central Namib desert, Namibia. *Cleome elegantissima* fringing a soil-filled depression at its margin

Fig.10.3.3. Ephemeral rock pool on the Spitzkoppe inhabitated by the poikilohydric *Chamaegigas intrepidus*

Fig.10.3.4. Sand blasted aerodynamic granitic inselbergs of the Uri-Hauchab archipelago in the center of the dunefield of the southern Central Namib. Note presence of water in rock pools and runoff vegetation, fringing the inselberg on its right-hand side

Fig.10.3.5. Tracks of runoff on dunes at the margin of the inselberg shown in Fig. 10.3.4

10.3.4 Climate

10.3.4.1 Regional Climate

In the Namib Desert, climatic gradients can be very steep and are of extreme importance (Lancaster and Lancaster 1984; Lindesay and Tyson 1990; Jürgens et al. 1997). Mild temperatures and high air humidity along the coast (cold upwelling Benguela current) contrast with the high temperatures and generally lower air humidity further inland. Fog is very frequent along the coast and often driven by southwesterly winds to regions far inland (Olivier 1995). The salt content of the fog decreases with distance from the coast. The southwestern part of the Namib, southwest of a line running from Lüderitz to the Eastern Cape receives winter rains. These are mainly provided by cyclonic winter rains developing over the Atlantic Ocean and normally form a soft drizzle. Rare events of convective rains associated with thunderstorms provide the highest rains in the tropical summer-rainfall zone, northeast of the boundary mentioned above.

10.3.4.2 Local Climate

Inselbergs are subject to special climatic conditions. Local climates on inselbergs, beyond the general decrease of temperature with increasing altitude, can be observed in two scenarios:

1. Inselbergs along the coast catch a lot of precipitation from fog and can therefore be described as fog oases. These are particularly favorable habitats for lichens and succulents. Examples are the Laguneberg in the Northern Central Namib. Vogelfederberg inland of Walvisbay, several inselbergs north and south of Lüderitz, and, especially, the Boegoeberg Twins and Aughrabies Mountains south of Alexanderbay. Generally, the importance of fog and dewfall is increasing with increasing altitude. However, fog events are often localized and may be limited to the lower parts of high inselbergs!
2. Large inselbergs like the Brandberg create their own circulation system of thermal uplift, being strong enough to create local cloud formation and rainfall. However, no quantitative data are available.

10.3.4.3 Microclimate

The high proportion of bare rock and runoff on rocky inselbergs obviously creates desert-like, unfavorable conditions for the vegetation on most of the surface. Therefore, in humid regions, inselbergs are edaphically arid and biologically relatively species-poor ecosystems.

In a desert environment with generally low precipitation in the whole landscape, the scenario is very different. Here, the high proportion of (unfavorable) rocky surface area creates a process of redistribution and concentration of available water and organic material to a very small surface area. This provides a higher and more predictable moisture supply which in combination with greater habitat diversity results in higher biodiversity on inselbergs than in the surrounding zonal habitats, a contrasting trend to inselbergs in humid regions.

Comparing different seasonal types of identical mean annual precipitation, the effect of concentration of moisture on inselbergs discussed here is low in those regions where precipitation is subdivided into numerous events of very low quantity (e.g., fog precipitation), thus leading to small runoff quantities. Very rare events of very high precipitation, in turn, will create strong (and destructive) runoff, accompanied by very long intervals of high aridity.

Depending on the size of catchment areas, the storage volume of the focus area collecting the runoff, and the characteristics of the regional climate, precipitation events of medium frequency and quantity will generally be more favorable than the two extremes given above.

10.3.5 Flora, Vegetation, and Life-Forms

10.3.5.1 General

The climatic division of the Namib Desert into a winter-rainfall part and a summer-rainfall part controls the phytogeographical pattern: the Namib Desert is divided into two very different floras. The succulent Karoo floral region, a part of the Greater Cape flora, is prominent in the southwest of the above mentioned climatic boundary, while the Nama Karoo floral region, part of the paleotropical floral kingdom, dominates northeast of the boundary.

Similarly, the vegetation units are separated into these major entities. Further subdivision of vegetation is controlled by:

- the complex gradient between coast and inland,
- the latitudinal complex gradient,
- major lithologically and geomorphologically defined landscapes,
- edaphical factors,
- local hydrological differences, and
- land-use systems.

Details have been reviewed in Jürgens et al. (1997).

In general, the floristic inventories of the inselbergs form part of the respective floristic unit in the particular area to which they belong. However, in the summer-rainfall part of the southern Namib Desert and the Great Dunefield, inselbergs house a large proportion of taxa, forming part of the Succulent Karoo phytochorion, which largely occurs in the winter-rainfall region. These populations have been interpreted as relict populations and can be interpreted as signs for a movement of the winter-rainfall system in a southwestern direction. However, the shift from Nama Karoo flora to Succulent Karoo flora can also at least partly be explained as a response to the altitudinal gradient in the inselbergs. Due to the steep ecological gradients in the Namib Desert, it seems adequate to discuss the inselbergs of the various regions separately.

10.3.5.2 Northern Namib Inselberg Archipelago

Inselbergs in the northern part of the Namib Desert present a mixture of foothills of the Hartmanns Mountains and granitic outcrops extending into the dune fields of the northern Namib. Surrounded by mobile dunes at their western side and sandy plains to the east, a preliminary analysis of the floristic composition of some of these inselbergs indicated some correlation with the inselbergs of the Great Namib dune fields. Dune-related species such as *Acanthosicyos horridus* and *Centropodia glauca* are present on both inselberg archipelagoes, although the flora of the northern Namib inselbergs is otherwise largely composed of taxa of paleotropic origin characteristic of summer-rainfall conditions. Many of these, such as *Commiphora anacardiifolia* and *Turnera oculata*, are endemic to this region, but possibly not restricted to the inselberg habitats. An interesting record at one of the northwesternmost inselbergs is the occurrence of *Sclerocarya birrea* var. *birrea*, a subspecies of a widely cultivated indigenous fruit tree in north-central Namibia. It may have been distributed by hunter-gatherers in the past.

10.3.5.3 Central Namib Inselberg Archipelago

An important center of inselbergs is found in the central Namib Desert between the river beds of Kuiseb and Ugab. In this area a very clear zonation of the zonal flora (Giess 1981) and vegetation (Hachfeld 1996; Jürgens et al. 1997) can be observed between the coast and the escarpment.

Next to the coast, outliers of the succulent Karoo flora like *Brownanthus kuntzii* and *Zygophyllum clavatum*, etc. occur together with lichens and the two most important species of the Central Namib, *Arthraerua leubnitziae*, and *Zygophyllum stapffii*. Further inland, *B. kuntzii* and *Z. clavatum* disappear and, still further inland, only *Zygophyllum stapffii* forms the majority of the biomass in the minimum zone of vegetation. Again further inland, with increasing importance of summer rainfall, grassland, and thorn savanna form the transition zone to the savanna biome.

In this region various types of inselbergs occur:

- huge crystalline inselberg massivs like the Brandberg,
- medium- and small-sized inland crystalline inselbergs like the Spitzkoppe, the Roessing Mountain, Blutkuppe, Messum mountains, etc.,
- small coastal inselbergs like Vogelfederberg and Laguneberg, and
- a network of linear dike structures of basaltic material (e.g., dolerite ridges), dissected into numerous inselbergs. These harbor a quite different flora and vegetation.

10.3.5.4 Brandberg

The Brandberg (2579 m) is a unique structure. This huge crystalline massif is a mountain range by its size and diversity, but an inselberg with respect to isolation and due to its very special vegetation, which is supported by an annual precipitation of about 100 mm in the upper parts of the mountain (Breunig 1990). The plant cover of the mountain is much more dense than in the surrounding semidesert or thorn shrub savanna vegetation. Probably it has been so for at least the past 4000 years, as numerous rock engravings and archeological sites in the Brandberg emphasize (Lennsen-Erz 1997). The flora of the Brandberg has been analyzed in detail by Nordenstam (1974, 1982), although there is no detailed account on vegetation. Nordenstam reports a strong altitudinal zonation with a number of temperate taxa at higher altitudes.

The Brandberg provides a diversity and magnitude of landscapes and habitats which goes far beyond the spectrum of habitats and geomor-

phological structures which are usually linked to the term inselberg. Therefore, more detailed information or analysis of the Brandberg is outside the scope of this chapter.

10.3.5.5 Medium- and Small-Sized Inland Crystalline Inselbergs

In contrast to the Brandberg, a number of medium- and small-sized crystalline inselbergs of the central Namib Desert present perfect examples for isolated granitic inselbergs. The most famous example is found in the Spitzkoppe group (Fig. 10.3.2 and 10.3.3). The rock surfaces themselves are bare of vegetation of vascular plants and only cyanobacteria and lichens form blackish crusts and brown margins along smaller drainage channels.

More interesting is the vegetation of seasonal rock pools which house specialists like the poikilohydric *Chamaegigas intrepidus* (Fig. 10.3.3 and 10.3.6). Also soil-filled depressions can accumulate and store a lot of water after seasonal rainfalls. Depending on soil depth and quantity of accumulated water, these depressions can show either rich herbaceous vegetation, e.g., with dominance of *Cleome elegantissima* (Fig. 10.3.2), or even woody elements, e.g., including *Dichrostachys cinerea*.

Fig. 10.3.6. The poikilohydric *Chamaegigas intrepidus* in a rock pool of the Spitzkoppe inselberg

Rock crevices and larger clefts are more favorable for growth of tall-stem succulent growth forms like *Moringa ovalifolia* (Fig. 10.3.7) and *Commiphora* spp., although nonsucculent rare local or regional endemics like *Nicotiana africana* (Giess 1982) are also found in this habitat type. In contrast, the poikilohydric *Myrothamnus flabellifolia* and several Acanthaceae prefer shallow substrate covers over rock. With increasing annual precipitation towards the east, monocotlyedonous mats dominated by *Xerophyta viscosa* gain in importance.

The flora and vegetation of only few inselbergs of the central Namib has been thoroughly inventoried. One example is presented here: the vascular flora of the Roessing mountain (U. Tränkle and F. Hübner, unpubl.), which includes 66 species. However, a comparison of this species inventory with the surrounding regions (Table 10.3.1) shows that not a single species of this inselberg is restricted to the mountain. All inselberg species are known also on the surrounding plains, provided rocky habitats of the plains are included in the comparison analysis.

Other central Namib inselbergs in a more isolated position with few rocky habitats on the surrounding plains, such as the group of granite

Fig. 10.3.7. Stem-succulent *Moringa ovalifolia* on rocky outcrops close to the Brandberg in the central Namib desert

Table 10.3.1. Roessingberg flora and its presence in surrounding habitats

Roessingberg	Plains	Rocky outcrops in plains	Hauchab	Family
Acanthosicyos horridus	0	0	H	Curcurbitaceae
Aloe asperifolia	0			Aloaceae
Anacampseros papillosus	0			Portulacaceae
Arthraerua leubnitziae	0			Amaranthaceae
Asclepias buchenaviana	0			Asclepiadaceae
Asparagus denudatus	0			Asparagaceae
Barleria lancifolia	0	0		Acanthaceae
Blepharis grossa	0	0		Acanthaceae
Citrullus ecirrhosus	0			Cucurbitaceae
Commiphora saxicola	0			Burseraceae
Cotyledon arborea	0			Crassulaceae
Dyerophytum africanum	0		H	Plumbaginaceae
Enneapogon scaber	0			Poaceae
Euphorbia gariepina	0			Euphorbiaceae
E. lignosa	0		H	Euphorbiaceae
E. mauretanica	0		H	Euphorbiaceae
E. phylloclada	0			Euphorbiaceae
Forsskaolea hereroensis	0			Urticaceae
Galenia fruticosa	0		H	Aizoaceae
Gazania jurineifolia spp. *scabra*	0			Asteraceae
Helichrysum roseo-niveum	0		H	Asteraceae
Heliotropium tubulosum	0			Boraginaceae
Hoodia currori	0			Asclepiadaceae
H. pedicellata	0			Asclepiadaceae
Hydnora sp.	0			Hydnoraceae
Hypertelis salsoloides	0			Molluginaceae
Juncus rigidus	0			Juncaceae
Kleinia longiflora	0	0		Asteraceae
Kohautia virgata	0			Rubiaceae
Lavrania marlothii	0			
Lithops ruschiorum	0			Aizoaceae
Lycium cinereum	0			Solanaceae
Mesembryanthemum guerichianum	0			Aizoaceae
Monechma arenicola	0			Acanthaceae
M. cleomoides	0			Acanthaceae
Orthanthera albida	0		H	Asclepiadaceae
Petalidium canescens	0	0		Acanthaceae
Petalidium variabile	0	0		Acanthaceae
Polygala pallida	0			Polygalaceae
Psilocaulon salicornioides	0			Aizoaceae
Rhus marlothii	0			Anacardiaceae
Sesuvium sesuvioides	0			Aizoaceae
Salsola tuberculata	0			Chenopodiaceae
Salvia gariepensis	0			Lamiaceae

Table 10.3.1 (*continued*)

Roessingberg	Plains	Rocky outcrops in plains	Hauchab	Family
Sarcocaulon patersonii	0			Geraniaceae
S. salmoniflora	0			Geraniaceae
Sarcostemma viminale	0			Asclepiadeaceae
Sporobolus consimilis	0			Poaceae
Stipagrostis schaeferi	0			Poaceae
S. ciliata	0		H	Poaceae
S. sp.	0			Poaceae
Suaeda merxmuelleri	0			Chenopodiaceae
Sutera maxii	0		H	Scrophulariaceae
Tamarix usneoides	0			Tamaricaceae
Tephrosia dregeana	0		H	Fabaceae
Tetragonia reduplicata	0			Aizoaceae
Trichodesma africanum	0			Boraginaceae
T. angustifolium	0			Boraginaceae
Zygophyllum cylindrifolium	0			Zygophyllaceae
Z. simplex	0			Zygophyllaceae

inselbergs in the Ganab area, show a slightly different trend: although many species occur in both habitats, inselberg and plains, there are several, such as the tree *Cordia sinensis* and the shrubs *Croton gratissimus*, *Hibiscus elliottiae*, and *Helichrysum tomentosulum*, which are restricted to these inselbergs.

10.3.5.6 Small Coastal Inselbergs

Far more special and isolated in its surrounding landscapes is the Laguneberg, a series of hills and smaller mountains close to the coast at the same altitude as the Brandberg. The Laguneberg mountains are very special due to the strong catchment of coastal fog, resulting in a very dense cover by lichens and succulents. Further south, similar structures are provided by the Swartbank and Vogelfederberg. Interestingly, the Swartbank mountains, which are slightly lower than Vogelfederberg and composed of marble, show a dominance of lichen species, while lichens are nearly absent from the granitic Vogelfederberg. The underlying chemistry of the substrate and differences in exposure to fog may explain these patterns, which warrant further investigation.

10.3.5.7 Dolorite Dikes

Between all these structures, linear inselberg archipelagoes are formed by the dolerite dikes of the Damara orogene. Single dikes – with minor interruptions due to erosion processes – sometimes reach a length of many tens of kilometers. The vertical size of these structures ranges from some meters or tens of meters in altitude in the normal case to up to 300 m in exceptional cases.

The flora and vegetation of these dolerite inselbergs is different from the surrounding plains. Firstly, several species like, e.g., *Pelargonium otaviense* and *Euphorbia virosa*, occur only on the dolerite dikes and not in the surrounding plains. Secondly, the species richness of the dolerite inselberg ridges lies generally high above the species richness in the surrounding habitat types plains and washes.

In a detailed analysis of the vegetation of the central Namib Desert plains, transects from the foggy coast to the inland have shown that the graph representing species richness on dolerite dikes is very different from the corresponding graphs for the habitat types of the surrounding plains (Fig. 10.3.8; Hachfeld 1996): while plain habitats show the lowest species

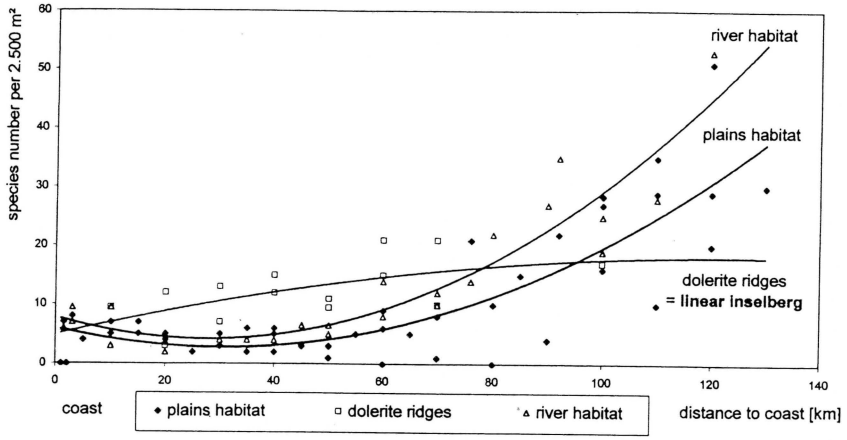

Fig. 10.3.8. Alpha-diversity along a transect cutting the central Namib Desert from coast (*left hand side*) to 120 km inland (*right-hand side*). Species richness of vascular plants on relevés of 2500 m² is shown for three habitat types, including linear inselbergs, formed by dolerite ridges. Biodiversity of the linear inselberg habitat shows steady increase from coast to inland and is higher than the biodiversity of plains and ephemeral river beds in the more arid parts of the Namib. With increasing precipitation further inland, species richness on the inselberg habitat is surpassed by plains and river bed habitats. (After Hachfeld 1996)

richness some 20 to 40 km inland from the coast, where neither coastal fog nor inland summer rain support higher vegetation, the graph for dolerite ridges shows more or less constant increase in species richness all along the transect from the coast to the inland escarpment. This curve may be explained by three factors: (1) the stronger fog-harvesting effect of the dolerite outcrops, combined, further inland, with (2) a relatively stronger response to the increasing, albeit low, amounts of summer rainfall, owing to the concentration effect by runoff from the rocky surfaces, and, still further inland, (3) the saturation of the limited water-storage capacity of rock fissures and crevices.

The graph also shows that species richness of the inselbergs is higher than the surrounding plains over the more arid western part of the transect. This relation is reversed at about 100 km inland: east of this position more species coexist in the plains than in the rocky dikes. This eastern scenario can perhaps be called the normal situation for tropical inselbergs, forming an arid island in a humid environment. The more arid 100 km of our Namib transect underlines that arid inselbergs, in contrast to the humid tropical scenario, possess higher biodiversity than the surrounding zonal habitats, due to a relatively higher moisture supply and higher habitat diversity.

10.3.5.8 Great Namib Dunefield Inselberg Archipelago

Another important archipelago of inselbergs is positioned in the Great Namib Dunefield with a maximum of density of inselbergs at the eastern margin of the dunefield close to the escarpment, but also including extremely isolated inselbergs like the Hauchab and the Blue Mountain. In the northeast, close to the Kuiseb Canyon, this sequence of inselbergs is nearly in contact with the central Namib inselberg archipelago. Again, isolated rocks in close vicinity to the coast like Sylvia Hill show very special environmental conditions and a specific flora. The occurrence of the locally endemic Mesemb *Jensenobotrya lossowiana* at the Spencer Bay hills forms the most famous example (Giess 1974; Robinson and Giess 1974).

All these inselbergs are very isolated with respect to the absolute interruption of rocky or stony habitat types between them: the matrix landscape of the whole region is formed by aeolian sandy deposits, mainly by dune sands without vegetation or with predominance of a few grass species, especially *Stipagrostis seelyae*, *Stipagrostis sabulicola*, and *Cladoraphis spinosa*; rarely a few more habitat specialists like *Monsonia ignorata* or *Trianthema hereroensis* are found. In striking contrast, the inselbergs show a very different composition. Already around the insel-

bergs a belt of *Stipagrostis lutescens* underlines the importance of the concentration effect of runoff from the rocky surfaces. On the mountains themselves, numerous species exist. As an example, the angiosperm flora of the Uri Hauchab archipelago in the center of the Great Namib Dunefield has been analyzed. The angiosperm flora of the Hauchab mountains is composed of 82 species with a large proportion of stem- and leaf-succulent taxa. Very interesting is the wide range of phytogeographical relationships of these species.

While the whole spectrum ranges from trees of the Sudano-Zambezian region of the Paleotropis to shrubs from the Greater Cape flora, the majority of species belongs to the Nama Karoo region of the Paleotropis (38 %) and the succulent Karoo region of the Greater Cape flora (19 %). For 42 % of the species, the Hauchab population forms an isolated locality in an extreme position in relation to the main area of distribution. Today, the Hauchab mountains are in the range of the summer rainfall climate, which should result in a Nama Karoo-related vegetation similar to the Roessing Mountain, shown above. However, as shown in the species list of the Roessing mountain (Tab. 10.3.1), very few of the Roessing species occur in the Hauchab as well. The high proportion of species with Greater Cape flora affinity could be attributed to a recent retreat of the succulent karoo flora after the last glaciation, but survival of many of these taxa in the inselberg situation owing to low immigration rate and resulting low competition.

10.3.5.9 Southern Namib Inselberg Archipelago

The region of highest density of inselbergs is found in the southern Namib Desert of Namibia in the vicinity of and between the two settlements Lüderitz and Oranjemund (Burke et al. 1998).

Overall, there is no doubt about the presence of numerous endemic species, like, e.g., *Microloma penicillatum*, *Pelargonium mirabile*, *Cynanchum meyeri*, and *Lessertia acanthorhachis*, all of which are associated with rocky habitats. Plant formations on the inselbergs show a strong contribution of leaf-succulent chamaephytes, while the surrounding plains are often dominated by grasses like *Stipagrostis ciliata*, *S. obtusa*, and *S. geminifolia*, or annuals like *Zygophyllum simplex*, in large parts also by the stem-succulent *Euphorbia gummifera*. A special element of those inselbergs which are within reach of the frequent sandstorms of the region are the psammophorous life-forms. Species like *Psammophora modesta* and *Psammophora nissenii* are well sheltered against the destructive force of sand-blasting by a layer of sand grains fixed to the surface of their leaves due to excreted sticky substances (Jürgens 1996).

The absence of detailed vegetation and floristic studies allows only a preliminary review and is not exhaustive. Complex geology and localized climatic influences call for a differentiation of these inselbergs into smaller units:

- low coastal outcrops,
- the Rechenberg-Tsaukhaib complex,
- Klinghardts Mountains, and
- eastern Sperrgebiet inselbergs.

10.3.5.10 Low Coastal Outcrops

Composed of metamorphic sediments such as gneiss, schist, and dolomite, low outcrops of less than 100 m above the surroundings occur all along the coast between Chameis and Lüderitz. They consist of isolated single outcrops and ridges and include spectacular rock features such as the Bogenfels Arch.

The flora of these coastal outcrops contains a large portion of regional endemic species – as high as 25 % (Burke 1997) – which could be attributed to their long isolation through mobile dune fields to the north and south from similar habitats along the coast. Many of these endemic species, such as *Eremothamnus marlothianus* and *Pelargonium cortusifolium*, are well adapted to thrive on low, but regular, moisture supply provided by fog and to endure strong, sand-blasting winds.

10.3.5.11 The Rechenberg-Tsaukhaib Complex

The inselbergs of the Rechenberg-Tsaukhaib complex are mostly composed of gneiss and granitic material and rise several hundred meters above their surroundings. A more southerly geographic position compared to the inselbergs of the Great Namib dunefield results in a larger component of species of the Cape Floristic region intermingled with regional endemics and a comparatively small (10–15 %) portion of species characteristic of summer rainfall conditions.

10.3.5.12 Klinghardts Mountains

The position of the Klinghardts Mountains in the southern Namib can be compared to the Brandberg Massif in the central Namib. Although not

reaching the same impressive altitudes – the highest peak is 1114 m – its closeness to the coast (30 km), its large extent over approximately 20 × 20 km, and its isolated position justify the comparison. Geologically, the Klinghardts Mountains comprise the above-mentioned metasediments of the surrounding rocky habitats (e.g., like those along the coast) and volcanic intrusions mainly in the form of phonolite. This mosaic of different subtrates in combination with fog influence resulted in a unique flora composed mainly of elements from neighboring floristic zones (Williamson 1997). Approximately 150 species have been recorded so far, mostly taxa of the Cape Floristic region and some species endemic to this mountain complex, e.g., *Strumaria phonolithica* and *Tromotriche ruschiana*.

10.3.5.13 Eastern Sperrgebiet Inselbergs

Although the group of eastern Namib inselbergs lumped together here varies in substrate and is exposed to often very localized special climatic conditions, their importance as refuges for species with high conservation status warrants a brief, descriptive account of some of the most striking features. The relative proximity to the escarpment and other large inland mountain complexes, such as the Huns Mountains and further south to the Namaqualand Broken Veld (Acocks 1988), is clearly reflected in the floristic composition of these inselbergs.

A western extension of black limestone and sandstones of the Nama group makes up the Tsaus Mountains and surrounding inselbergs (Geological Survey 1980). The mountains form a flat plateau with steep slopes and are characterized by relatively low species richness with a larger portion of summer-rainfall taxa than the inselbergs north and south of Tsaus. Examples include several *Pteronia* species, *Kleinia longiflora*, and *Trianthema triquetra*. Evidently restricted to black limestone and dolomite is the regional endemic *Euclea asperrima*, which can also be found on dolomites of the Naukluft Mountains, some 300 km north of the Tsaus Mountains. The Aurus Mountains show the highest plant diversity and density of vegetation in the southern Namib (Williamson 1997). While the western slopes rise steeply from the surrounding plains, forming a barrier to catch and force fog clouds to ascent over the saddle, the interior and eastern part of the mountains descend gradually into the eastern plains. Protected by the southern and western ridges from the usually strong southwesterly winds and receiving additional moisture from fog, the interior of the mountains supports a diverse and dense vegetation, accompanied by many taller plants and moisture-loving taxa usually absent in this part of the Namib Desert. Examples include the trees *Aloe*

ramosissima, *Maerua gilgii*, *Ozoroa dispar*, the desert orchid *Holothrix filicornis*, and several ferns and mosses. The southeastern corner of the southern Namib holds an array of inselbergs of various sizes mainly composed of quartzite, schist, and dolomite forming a transition to the foothills of the escarpment. The most prominent outposts are the Obib Mountains, where the presence of some taxa typical of the Richtersveld flora, such as *Aloe pearsonii*, indicates the transition to the Namaqualand-Richtersveld flora.

10.3.5.14 Northern Namaqualand-Richtersveld Sandfield Granite Inselbergs Archipelago

While in the mountains of Namaqualand (Northern Cape Province, RSA) numerous huge granite domes form parts of an uninterrupted mountain range and hence cannot be called inselbergs, similar, but isolated mountains are found in the sandfield of Coastal Namaqualand. This archipelago includes numerous more or less isolated mountains and hills from the Boegoe Twins south of Alexanderbay (van Jaarsveld 1987) or the Aughrabies Mountains near Port Nolloth to the Buffels River and further south. Due to the generally high air humidity and high incidence of fog in this coastal region, lichens and small leaf succulents reach extreme species numbers in these inselbergs. On the southwestern slope of the Boegoe mountains near Alexanderbay, lichens have formed pioneer vegetation which accumulated downslope on moving substrate. In later successional stages small leaf-succulent species including *Tylecodon schaeferanus*, *Conophytum saxetanum*, and *Senecio phonolithicus* established themselves on the microterraces thus formed. Through this process, sheer rock surfaces are transferred to species-rich mosaics of vegetation units of different soil depth and age (N. Jürgens, pers. observ.).

10.3.6 Human Impact and Conservation

As oases in an arid environment, the inselbergs of the Namib Desert are of high conservation value, which house a rich flora and many endemic taxa. Although the example of the Roessingberg in the central Namib (Tab. 10.3.1) has shown that very many species of the surrounding plains also exist on the inselbergs, examples of inselbergs in the southern Namib indicate the presence of endemic species restricted to these mountains. This is a general pattern due to the high diversity of microenvironments on

inselbergs which normally includes a large part of the spectrum of habitat conditions of the surrounding plains. Therefore, inselbergs possess a very high regeneration potential for the flora of the zonal environments, a fact which can be of great importance when natural environmental oscillations or man-made degradation destroy the flora of the zonal habitats. Therefore, conservation of inselbergs should receive great attention.

Fortunately, in the Namib Desert, the actual protection status is relatively good due to the low intensity of human impact and the high proportion of inselbergs being included in conservation areas, consequently already falling under formal protection. Nevertheless, those inselbergs not included in conservation areas, such as the Brandberg and surrounding inselbergs, experience severe impacts due to increasing tourism and/or increasing grazing pressure and land use for small stock farming. This forms a potential threat to the flora of these inselbergs in the future.

In addition, the inselberg flora of the southern Namib contains many rare plant species sought for by succulent collectors. Although currently most of these inselbergs are difficult to access, the potential opening up of the restricted Diamond Area for tourism, may call for special measures and protection status for inselbergs in this area.

10.3.7 Research Needs

Although data on inselberg floras in many parts of the Namib are still lacking, the largely descriptive approach of the authors points clearly to a need for a comprehensive review and analysis of current data. Questions related to the origin and development of the Namibian flora, migration routes, and distribution patterns are some relevant research topics. Understanding ecological processes and environmental factors responsible for the distribution of inselberg floras will contribute invaluable information to establishing conservation needs, identifying potential threats, and evaluating inselberg floras in the light of regeneration potential of degraded areas.

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